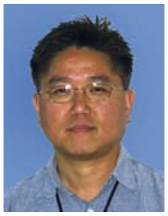
Modeling Forming Processes



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The ability to model and optimize material manufacturing processes and predict resulting material properties is important where product performance, costs and/or waste reduction are concerns. DOE programs such as Reliable Replacement Warhead (RRW), Transformational Materials Initiative (TMI), and Responsive Infrastructure (RI) will rely on rapid prototyping of complex components. The goal of process modeling is to provide a simulation-based, rapid-design capability for efficient production of high quality parts with better control over the desired properties. Application of process tools will reduce trial and production costs and shorten the time from product conception to production. Detailed understanding of material response and product performance predictions can be achieved by combining robust finite element simulation tools from DOE's ASC program with advanced models of material properties.

Project Goals

The goal of this project is to demonstrate advanced material modeling capability for forming process simulation and to work with production laboratories toward validating the models. The capability will be valuable in the design and optimization of forming processes to achieve desired microstructures, properties, and performance characteristics.

Relevance to LLNL Mission

This effort will contribute to LLNL's role and core competency in numerical modeling and material response. The capability demonstrated in this project is supportive of other forming processes where geometric fidelity and control of material properties are critical.

FY2006 Accomplishments and Results

A material model for static recrystallization has been implemented into ALE3D for use in forming process

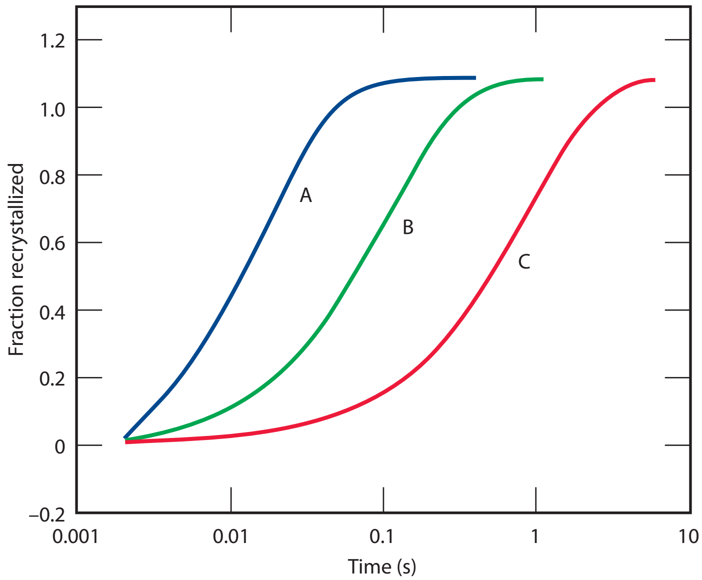

Figure 1. Recrystallized fraction plotted against time for aluminum.
For A: $\dot{\varepsilon} = 10^{-7}\ s^{-1}$, $\varepsilon = 0.3$; for B: $\dot{\varepsilon} = 0.1\ s^{-1}$, $\varepsilon = 0.3$; and for C: $\dot{\varepsilon} = 10^{-7}\ s^{-1}$, $\varepsilon = 0.3$.

simulations. The model is based on microstructure parameters such as grain size; prior deformation that creates a forest dislocation structure; and the Zener-Hollomon parameter, which is a function of temperature and strain rate. The model accounts for the material strength reduction resulting from dissolution of the forest dislocation structure as the grains recrystallize. Figure 1 shows a typical range of fraction recrystallized as a function of time following deformation under various strain and strain rate conditions.

A rolling simulation of an aluminum slab was performed for validation, and a contour plot of recrystallized fraction at the end of the first pass is given in Fig. 2. The figure shows that the most recrystallized portion of the rolled slab is the offset from the top and bottom surfaces since the strain is higher at these locations. The variation in strength levels across the slab thickness results from a combination of increased strength due to strain hardening and strength reduction from recrystallization.

Also, demonstrations of shock processing simulations of porous materials were performed. A constrained-random void configuration model was constructed as shown in Fig. 3, where, under shock conditions, these voids collapse. The collapsing voids can significantly alter local stress fields, and at the same time the temperature can increase dramatically. The shock-processed material is subsequently deformed, so the effect of this prior processing on the material performance is of great importance. A series of simulations using different shock conditions, ranging from 10 GPa to 40 GPa, were carried out to demonstrate capability for constructing equation-of-state models for a porous material (Fig. 4). The figure reveals that different values of bulk modulus were observed, depending on the level of initial pressure conditions.

Related Reference

Bontcheva, N., and G. Petzov, "Microstructure Evolution During Metal Forming Process," *Computational Materials Science*, **28**, pp. 563-573, 2003.

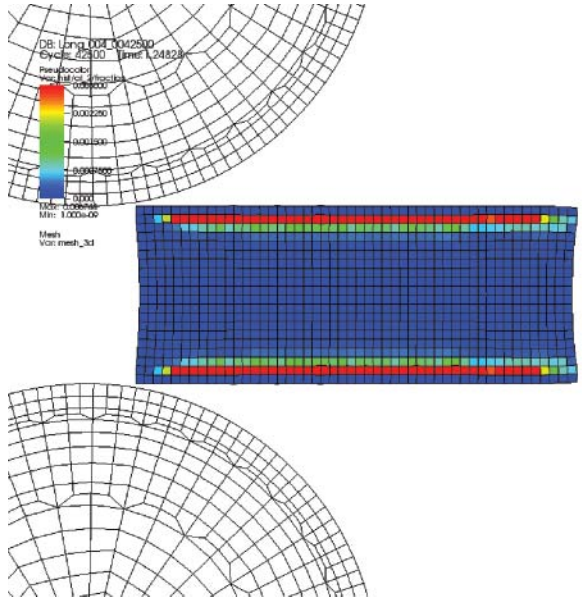

Figure 2. Hot rolling simulation of aluminum at 700 K. Red colors at the second element from the top and bottom surfaces indicate highest portion of recrystallization.

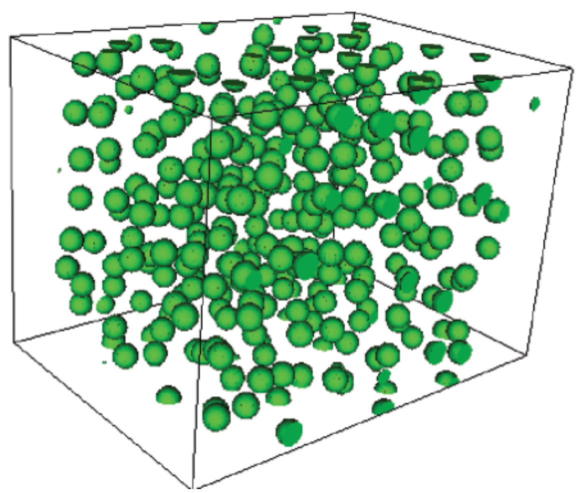

Figure 3. Constrained-random void distribution, 10 % void fraction.

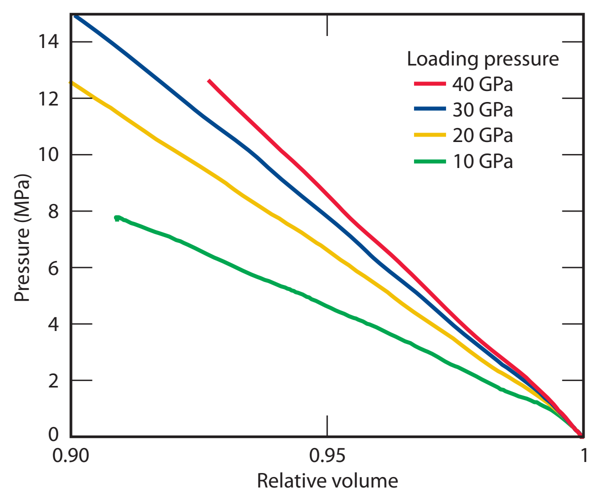

Figure 4. Elasticity pressure vs. relative volume for void configuration given in Fig. 3.